U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Technical News

BULLETIN

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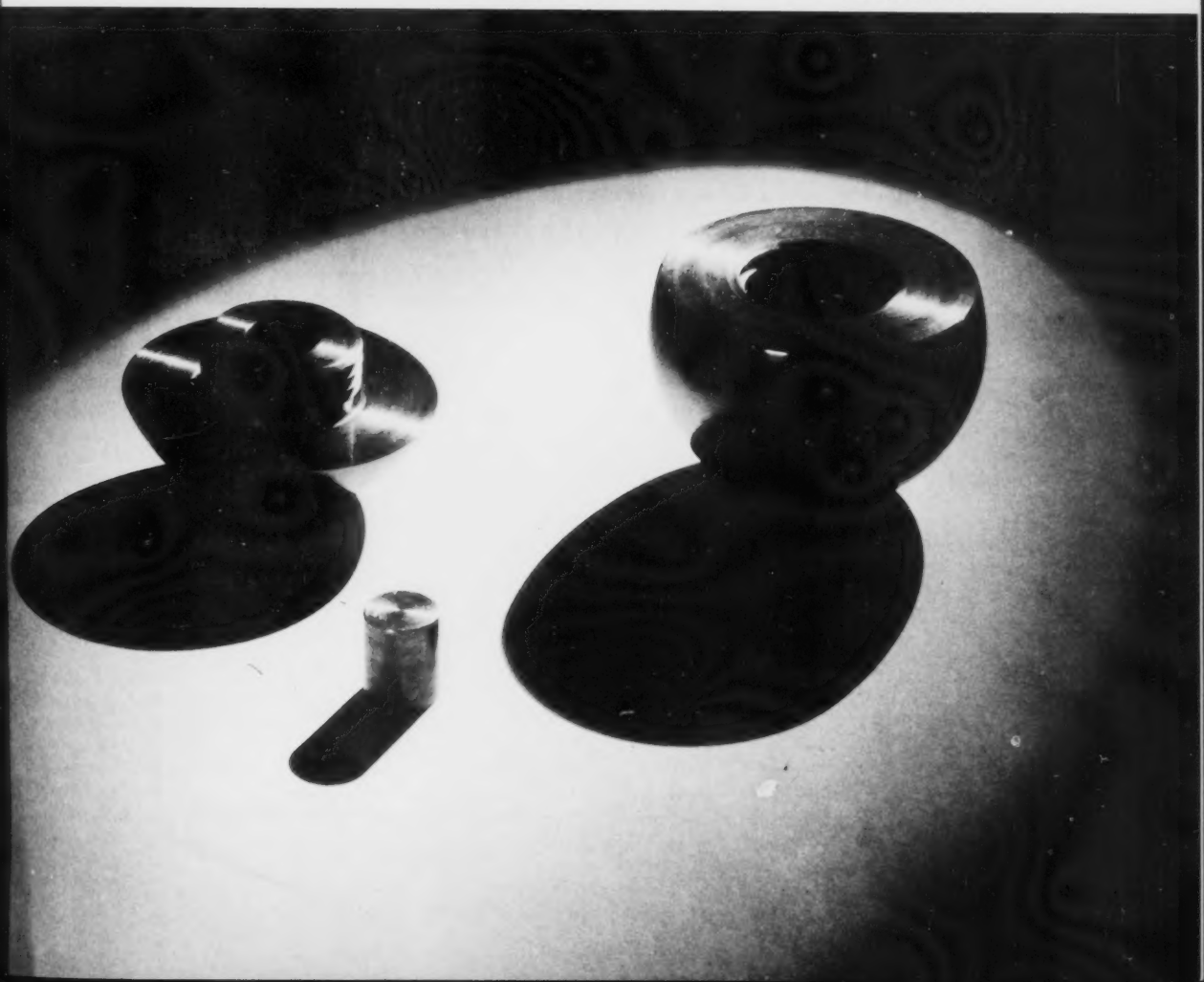

U.S. DEPARTMENT OF COMMERCE — LUTHER H. HODGES, *Secretary*

NATIONAL BUREAU OF STANDARDS — A. V. ASTIN, *Director*

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Contents

COVER: Disassembled replica (4 cm diam) of the national neutron standard maintained by the National Bureau of Standards. Neutrons are produced through the action of gamma rays (coming from radium within the platinum-iridium cylinder), on the outer beryllium sphere. Starting from this basis, the Bureau calibrates neutron sources used in a wide variety of applications in science and industry (see p. 38).

Scattering From a

COBALT 60 CALIBRATING SOURCE

IT IS OFTEN assumed that gamma-radiation beams from large cobalt 60 sources contain 1.17- and 1.33-Mev photons only. However, energy degradation resulting from Compton scattering of the radiation produces a spectrum of many energies. In calibration work, especially in the intercomparison of instruments in different laboratories, the ability to define the spectrum is important, as many instruments are energy dependent. It is also important to know the radiation spectrum in therapeutic treatments, as the beam energy, and thus the dose absorbed in the patient's body, is dependent upon the amount of scattering.

L. Costrell, chief of the nucleonic instrumentation laboratory, has made an experimental determination of the amount and energy of scattered radiation coming from large cobalt 60 sources. The results of this determination can be used to estimate the amount of scattered radiation arising in the various components of typical multicurie calibrating and radiology sources.

Scattering can arise in four components of a cobalt 60 source—the source material itself, the capsule, the head, and the collimator. To determine the amount of scatter arising in each of these components, measurements were made on a series of sources, fabricated to simulate a wide range of conditions.

Measurements of beam spectra were made with a scintillation spectrometer, the detector of which consisted of a thallium-activated sodium iodide crystal 4 in. long and 5 in. in diameter, and a 5-in. photomultiplier tube. A 12-in.-long lead collimator, placed in front of the crystal, limited the diameter of the impingent beam to 1.5 in. The spectra were accumulated in one-half the memory of a 256-channel pulse-height analyzer; the background spectrum was recorded in the other half and subtracted from the data of each run. A tiny cobalt cylinder containing about 1 mc of cobalt 60 was used to determine the response of the detector to an essentially zero-scatter source.

Procedure

A series of steps was required to determine the scattered radiation spectrum for each source. First, a curve of count-rate versus energy absorbed in the scintillator was obtained for the "zero scatter" source. Using this curve, the photofraction and detector efficiency were determined as a function of energy. Then curves of count versus energy were obtained for the various sources and normalized to the same integrated count rate in the photopeak as the zero scatter curve. The latter curve was subtraced from the normalized curve for each source and the difference curves were plotted to correspond to a total count rate of 100 in the photopeaks. The photofraction and efficiency data were used along with curves of the detector response to monoenergetic photons to construct a matrix which was inverted on a computer to "unscramble" the difference curves and give curves of scattered photons versus scattered photon energy.

This procedure was necessary because of those Compton collisions within the crystal in which the scattered photon (or its descendent) escapes from the crystal. In such cases the energy absorbed in the crystal is less than the energy of the impinging quanta. Thus, some of the counts at any given energy are contributed by gamma-ray photons of higher energy. The unscrambling has taken this into account in converting "count-rate" curves to "incident photon" curves. Finally, curves of radiation intensity versus photon energy were obtained by weighting the number of photons in the curves by the energy and normalizing to a total intensity of 100 in the photopeaks.

Results

The results of this investigation [1] show that the encapsulated source material contributes heavily to the scattered radiation. Therefore, low-scatter multicurie sources must utilize material of high specific activity. One of the sources used, simulating a widely used teletherapy source and consisting of a basic encapsulated source surrounded by steel shot to simulate cobalt 60 pellets, was found to scatter 13.3 percent of the total radiation. With a head emplaced, 15.4 percent was scattered, and with a head and collimator, 14.6 percent. The other sources, having smaller masses, scattered correspondingly less radiation.

[1] *For further information, see* Scattered radiation from large cobalt 60 calibrating sources, *by L. Costrell, Health Physics (to be published in June 1962).*

H. O. Cline examines the detector assembly used in measuring the amount of scattering occurring in typical cobalt 60 gamma ray sources. The detector consists of a sodium iodide crystal, a photomultiplier, and a preamplifier. The lead shielding bricks and lead collimator are in the foreground. The associated counting equipment is shown in the background.

Calibration of Neutron Sources

Ninth of a Series on NBS Measurement Service*

Above, a spherical steel tank (2 ft. diam.) containing manganous sulfate solution is used in the calibration of neutron sources having a low activity, as the dilution factor is smaller than for an open tank. The probe enters through the top and is connected to counting equipment.

NEUTRON SOURCES are used in a wide variety of scientific applications, including the production of radioisotopes, the study of the structure of atoms and nuclei, and the initiation of fission. The emission rate of these sources must be accurately known if they are to be used with maximum effectiveness. The Bureau assists users of neutron sources by determining the activity of unknown sources [1]—relative to the national neutron standard [2]—over the range 10^4 to 10^7 neutrons per second (n/s).

The neutron, a fundamental particle, was discovered by Chadwick in 1932. In mass it is almost identical with the proton and, as its name implies, is electrically neutral. This lack of charge enables neutrons to penetrate the nuclei of atoms quite easily, as they are not repelled by the charge of the nucleus. The capture of a neutron by a nucleus results in the production of a heavier, often radioactive, isotope of the given element. It is this ability to penetrate nuclei that makes neutrons so important in modern technology.

National Neutron Standard

The national neutron standard source, NBS–1, consists of an aluminum-covered beryllium sphere, inside of which is a platinum-iridium capsule containing 1 g of radium in the form of radium bromide. Neutrons are released from this source by the action of gamma rays from the radium on the beryllium: Ra-Be (γ,n). Such a source is preferred as a standard to a Ra-Be (α,n) source, as the emission rate of the latter changes slowly because of the growth of polonium. In NBS–1, (α,n) reactions are prevented by the platinum-iridium capsule, which blocks the passage of alpha particles.

A second source, NBS–2, closely resembling the national standard, has been fabricated and its emission rate compared with NBS–1. The national standard remains at the Bureau; NBS–2 has been used extensively in international intercomparisons of neutron sources. The Bureau also has 5 plutonium-beryllium (α,n) working standard sources, used in the graphite pile to calibrate sources of low activity.

Standard Source Calibration

The absolute emission rate of NBS–1 has been measured by two independent methods.[3] In the first of these, the thermal neutron density was determined from the activity induced in thin indium and magnesium foils as a function of distance from the source when both the source and foils were under water. The second method involved the capture of neutrons by a surrounding manganese sulfate ($MnSO_4$) bath, followed by counting the gamma activity of the manganese 56. The final value of NBS–1, the national standard, is $1.26_4 \times 10^6$ n/s.

As the half-life of radium is 1622 years, the emission rate of the standard is constant over a long period of time. The emission rates of both NBS–2 [4] and the Pu-Be sources are determined by comparison with NBS–1 in the $MnSO_4$ bath.

Calibration of Submitted Sources

Sources having emission rates in the range 10^5 to 10^7 n/s are calibrated by comparison with NBS–1 in a large open tank, 1 m in diameter, containing $MnSO_4$ solution to a depth of 1 m. Calibrations made with this method depend upon measurement of the gamma activity induced in manganese through the capture of neutrons, and are accurate to within 3 percent.

Before calibration begins, a background count is made by immersing a sodium iodide scintillator (housed in a stainless steel dip probe) in an accurately reproducible position at the center of the tank. Then the probe is removed and the standard source is suspended at the center for about 18 hr. The source is enclosed within a graphite block which serves to minimize the correction necessary for absorption of thermal neutrons by the source itself. After removal of the source, the solution is stirred for 5 to 10 min. Then the dip probe is positioned near the inside wall of the tank, and a small cesium 137 source is placed opposite the probe on the outside of the tank. The electronic counting system is adjusted in terms of the cesium 137 pulse height. The probe is then positioned in the center of the tank, a 20-min count is made, and the pulse height rechecked. This counting procedure is repeated 4 to 8 times.

**Previous articles have been:* Calibration of gage blocks, *Feb. 1961*; Thermocouple calibrations, *Mar. 1961*; Calibration of platinum resistance thermometers, *Apr. 1961*; Calibration of inductive voltage dividers, *May 1961*; X- and gamma-ray calibration, *July 1961*; Calibration of optical pyrometers, *Nov. 1961*; Calibration of microphones, *Nov. 1961*; and Calibration of flowmeters for liquid hydrocarbons, *Feb. 1962*.

Neutron sources of low activity are often calibrated in a graphite pile. Here C. B. Childers positions a boron-lined counter in the pile. The unknown—or standard—source will be placed in the cavity seen in the partially withdrawn rod near the bottom, and will be positioned within the pile before counting begins.

The source to be calibrated is then immersed in the solution for 18 hr. After removal of the source, the same counting procedure as that for NBS–1 is followed. The entire standard-unknown comparison is repeated 2 to 4 times before final calculations are made.

A smaller spherical tank is used for calibrations of (γ, n) neutron sources in the range from below 10^5 n/s to 10^6 n/s. Weaker sources may be calibrated with this tank as the dilution of the activity is less than in the cylindrical tank. Sources in which neutrons are produced by the action of alpha rays cannot be used because the escape of neutrons from the tank is too great. The calibration techniques employed with this apparatus are the same as those used with the larger tank.

Sources having activities as low as 10^4 n/s are often calibrated in a graphite pile. A comparison is made in the pile between the activities of the unknown source and of one of the Bureau Pu-Be sources, the latter having been compared with NBS–1 in the large tank prior to use. First, the standard source is placed within a depression cut in one of the graphite elements of the pile, and positioned near the center of the pile. A boron-lined detector, connected to an electronic counting system, is then placed within the pile at a point above the source that will result in a favorable counting rate. From six to eight 100-sec counts are taken of the standard; then the standard source is replaced with the unknown and a similar number of counts taken. The emission rate of the unknown is then related—indirectly through the (α, n) source—to NBS–1. Relative calibrations made in this manner are also accurate to within 3 percent, the final overall accuracy being about 5 percent.

C. B. Childers positions a dip probe in a manganous sulfate bath prior to making a count of neutron background activity. The bath is used during the calibration of neutron sources relative to the national standard source.

Neutron Research

The Bureau not only calibrates neutron sources, but conducts a comprehensive research program in other areas of neutron physics as well.[5] Such topics as the shape of the nucleus,[6] neutron cross sections, the age of neutrons in water, and neutron flux and dose measurement have been or are being investigated.[7] In addition, a high-flux reactor [8] has been designed and will be installed at the Bureau's new Gaithersburg (Md.) facilities. As the reactor's initial inpile flux will be 10^{14} n/cm^2, the Bureau's capabilities in neutron calibration and research will be greatly extended.

[1] *See* Test Fee Schedules of the National Bureau of Standards *available from the Office of Technical Information, NBS, Washington 25, D.C.*

[2] A permanent standard of neutron intensity, *NBS Tech. News Bull.* **34,** *1 (Jan. 1950).*

[3] Absolute calibration of the National Bureau of Standards photoneutron standard: I, *by J. A. DeJuren, D. W. Padgett, and L. F. Curtiss, J. Research NBS* **55,** *63 (Aug. 1955). See also* Absolute calibration of the National Bureau of Standards photoneutron standard: II, *James DeJuren and Jack Chin, J. Research NBS* **55,** *311 (Dec. 1955).*

[4] Scintillation counter method of intercomparing neutron source strengths by means of a manganous sulfate bath, *Earl R. Mosburg, Jr., J. Research NBS* **62,** *189 (May 1959).*

[5] Neutron physics research at the NBS, *NBS Tech. News Bull.* **43,** *56 (Mar. 1959).*

[6] Shape of the atomic nucleus, *NBS Tech. News Bull.* **43,** *45 (Mar. 1959).*

[7] Age to indium resonance for D-D neutrons in heavy water, *by V. Spiegel, Jr., and A. C. B. Richardson, Nuclear Sci. and Eng.* **10,** *11 (May 1961).* A recalibration of the NBS standard thermal neutron flux, *by E. R. Mosburg, Jr., and W. M. Murphey, Reactor Sci. and Technol.* **14,** *25 (1961).* Neutron insensitive proportional counter for gamma-ray dosimetry, *by Randall S. Caswell, RSI* **31,** *869 (Aug. 1960).*

[8] High-flux research reactor, *NBS Tech. News Bull.* **45,** *127 (Aug. 1961).*

U.S.-U.K. Intercomparison of RF Power Standards

A SMALL, stable, and rugged interlaboratory standard for radiofrequency power has been developed by the Bureau [1] and has recently been used to compare RF power measurement standards at 300 Mc/s with the United Kingdom. This is the first time that power standards have been compared internationally in this frequency range.

The international comparison, made in accordance with long-standing recommendations of the International Scientific Radio Union (URSI), revealed agreement between the two countries within 0.5 percent and thus provides greater confidence in the RF power standards of both countries. The Bureau is now seeking comparison of power standards with other countries at both 300 and 1,000 Mc/s.

At the NBS Radio Standards Laboratory the national reference standards for the measurement of RF power below 1,000 Mc/s consist of calorimetric-type power meters and bolometer bridges. The versatility of these standards is limited because of their relatively long response time and the fact that they absorb the measured power. For this reason comparison with other absorption-type meters becomes very difficult and is subject to error unless elaborate precautions are taken.

The new instrument can be used either as a sensitive interlaboratory standard or as a calibrated power meter. In either case it merely samples the power. The instrument is stable; it has high resolution and a fast response, and can be used to measure power into a wide range of load impedances. Its rugged construction is pointed up by the fact that it was shipped as normal air parcel post from Boulder, Colo., to London, England. Its stability under these conditions, plus its other features, accents its potential for general use within the laboratory.

The special 300 Mc/s interlaboratory standard was designed, built, and calibrated by a group headed by Paul A. Hudson within the NBS Radio Standards Laboratory at Boulder. It consists of a 300-Mc/s quarter-wave directional coupler and a thermoelement mount.

Comparison measurements were made in the United Kingdom at the Radio Research Station of the Department of Scientific and Industrial Research and were carried out in collaboration with the Ministry of Aviation. Values obtained by the comparison are shown in the table (below).

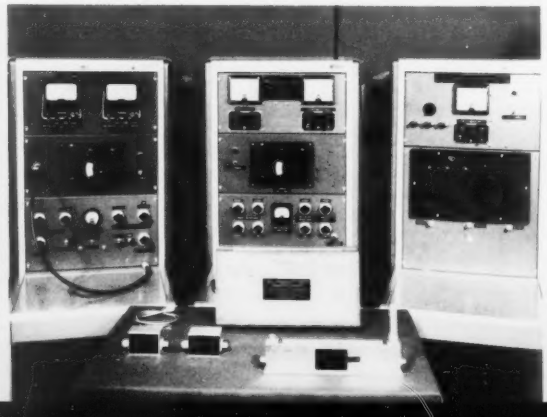
NBS mount	Power range	Average difference, $\frac{\text{U.S.}}{\text{U.K.}}$
Comparison with thermionic diode power meter		
No. 1	*mw* 50–400	% +0.19
	100	+.50
No. 2	50–400	+.27
	100	+.30
Comparison with thermistor mount		
No. 1	50–400	−0.24
	100	+.20
No. 2	100	+.20

Plus (+) indicates that the U.S. standard was high.

The interlaboratory standard used in the international comparison is designed for optimum directivity and sensitivity at 300 Mc/s. The Bureau, however, has designed and built similar transfer standards—for relatively broad bandwiths—to cover the frequency range of 10 to 1,000 Mc/s at the following fixed frequencies: 10, 30, 100, 200, 300, 400, 500, 700, and 1,000 Mc/s. These require three directional couplers to cover the entire range and, also, a thermoelement mount matched to 50 ohms at each frequency. The basic power range of the coupler-thermoelement combinations is 50 to 500 mw and may be extended to 1,000 w with calibrated attenuators.

Direct calibration of the interlaboratory standards can be accomplished by measuring power through the

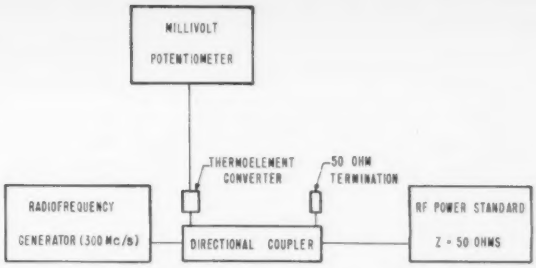
Left: **P. Hudson calibrates the new interlaboratory RF power standard with the NBS medium power bolometer bridge. The standard is in center foreground. In background, left to right, are the RF generator, d-c voltage measuring equipment, and the medium power bolometer bridge.** ***Right:*** **Before and after being shipped to London, the standard (*foreground*), was calibrated with reference to three national measurement standards: RF power-measuring bridge (*left*), medium power bolometer bridge (*center*), and the calorimetric RF power meter (*right*).**



primary line of the coupler with one of the national reference power standards and observing the d-c voltage output from the thermoelement on an accurate millivolt potentiometer. Alternatively, each part of the unit can be calibrated separately by determining the coupling ratio of the coupler, the insertion loss of each step of the attenuator, and the power sensitivity of the thermoelement. Power through the primary line of the directional coupler is then simply the product of the power detected by the thermoelement multiplied by the coupling ratio and the attenuator ratio. Both forward and reflected power can be measured separately by interchanging the thermoelement and the 50-ohm termination on the secondary outputs. Thus, it is possible to calculate the net power into a mismatched load by subtracting the reflected from the forward power.

In ordinary use as a calibrated RF power meter the device has an accumulated uncertainties total of approximately 1 percent. That is, the coupling ratio and attenuator insertion-loss ratios are each measured within 0.2 percent, while the calibration accuracy of the thermoelement power sensitivity is within 0.5 percent. Another 0.2 percent is added because the data do not exactly fit the averaged calibration curve at all points.

Measurement accuracy of net power into a mismatched load is retained for VSWR's up to 3. However, if the generator is not matched (giving rise to multiple reflections), or if the coupler is poorly constructed, a larger error can result.[2] The overall accuracy was verified by comparing the interlaboratory standard with the standard bolometer bridge and calorimeters.



Typical setup for calibration of an interlaboratory standard for RF power.

Resolution of the instrument when used as a standard or monitor varies from 0.1 percent to 0.01 percent at d-c outputs of 1 mv and 10 mv, respectively. This is considered adequate because the resolution is at least an order of magnitude better than the absolute accuracies obtained.

Aging effects in the thermoelements and their associated pi-matching networks were negligible at the resolution used in this work. The thermoelements were sealed in vacuum and the matching networks employed air-core inductors and air-dielectric capacitors. In addition, normal variations in room temperature and humidity had no noticeable effect on the d-c output of the thermoelements.

[1] A precision RF power transfer standard, *P. A. Hudson, IRE Trans. Instr.* **1–9,** *No. 2, 280 (Sept. 1950).*

[2] Mismatch error in microwave power measurements, *R. W. Beatty and A. C. Macpherson, Proc. IRE* **41,** *No. 9, 1112–1119 (Sept. 1953).*

Plans Announced for 1963 International Symposium on Humidity and Moisture

AN "International Symposium on Humidity and Moisture—Measurement and Control in Science and Industry" will be held May 20–23, 1963 in Washington, D.C. Designed to present the "state of the art" in the measurement and control of humidity and moisture in the physical, engineering, agricultural, and biological sciences, the symposium is jointly sponsored by the National Bureau of Standards and the Weather Bureau of the U.S. Department of Commerce, and three technical societies, the Instrument Society of America, American Meteorological Society, and the American Society of Heating, Refrigerating, and Air Conditioning Engineers. Headquarters for the meeting will be the Sheraton-Park Hotel.

This will be the first international conference devoted exclusively to this subject and the first symposium since November 25, 1921, when a meeting was held at the Imperial College in London. It will provide an opportunity for scientists and engineers to review the state of the art, to exchange information, and to learn of the latest developments in such widespread fields as meteorology, agriculture, drying, refrigeration, storage, aerology, materials conditioning, testing and manufacturing, compressed gas manufacturing, natural gas transmissions, and in such disciplines as physics, chemistry, biology, and engineering.

It is planned to arrange the meeting into sessions devoted to such areas of interest as the following:

(1) *Fundamentals.* Properties of water vapor and water vapor–gas mixtures; effect of water vapor on the transport properties of mixtures, relaxation time, and the association of coefficients; physical and chemical properties which make possible operating principles for measuring humidity; definitions and units; saturation vapor pressure formulas and tables; departures of gas laws from ideality for water vapor–gas mixtures, particularly at high pressures.

(2) *Standards.* Humidity standards, generators, and hygrometer test equipment; methods of test and calibration; chambers and test rooms for conditioning and testing materials; methods of establishing fixed humidities.

(3) *Hygrometers and moisture detectors.* New, improved, or more accurate indicators, recorders, and methods of measurement; critical reviews, surveys, and bibliographies of various classes of instruments or methods of measurement; present and anticipated requirements of various fields and disciplines as to range, environmental conditions, required accuracies, speeds of response, size, weight, etc.

(4) *Applications.* Measurements unique or special to various fields or disciplines; studies and investigations in which humidity or moisture is the critical parameter.

(5) *Methods of control.* Humidistats, controllers, air conditioning techniques, methods of humidification and drying.

Both invited and contributed papers will be presented at the symposium. All accepted proceedings papers will be published in book form. Those interested in presenting papers are invited to submit two copies of an abstract to Arnold Wexler, Chairman of the Program Committee, National Bureau of Standards, Washington 25, D.C.

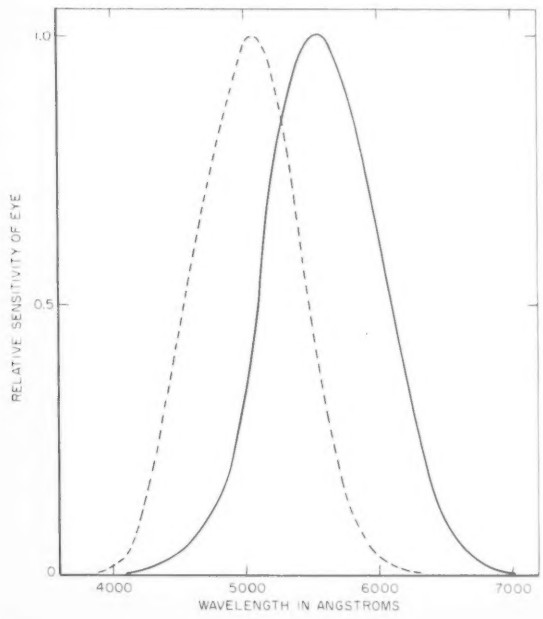
AURORAL ARCS IN MID-AT

SINCE ancient times men have marveled at the beauty of the aurora and at its kaleidoscopic changes in form and color. The earliest serious observations of the aurora were, of course, visual. During the nineteenth century systematic observations indicated that in both the Northern and Southern Hemispheres there are regions of maximum occurrence, now called auroral zones, which are roughly symmetrical with respect to the earth's magnetic poles. The rationalization of the auroral zones has preoccupied many of those who have attempted auroral hypotheses.

During the period of the International Geophysical Year and the International Geophysical Cooperation Year a new family of auroral arcs was found to occur in mid-latitudes. These arcs had previously escaped detection because they are monochromatic, involving an optical emission in the red region (6300 A) to which the human eye is relatively insensitive.

Just as the visible auroras tend to occur predominately in certain geographical regions or auroral zones (in circles about 23° from the magnetic pole), so the newly discovered arcs show a preference for particular latitudes (about 40° from the magnetic poles). The Fritz Peak (Colo.) Geophysical Observatory of the Central Radio Propagation Laboratory (NBS Boulder, Colo., Laboratory) is near the center of this second zone. Consequently the Airglow-Aurora Section of the Upper Atmosphere and Space Physics Division has been active in photometric study of these arcs. In the last four years this group has used photoelectric photometers sensitive to the red emission (6300 A) to determine such properties of these arcs as height, intensity, and position.

***Figure 1*, relative color sensitivity of the eye when adapted to bright (*solid line*) and faint (*dashed line*) light.**



Visual Observations

The proper evaluation of the large accumulation of visual auroral observations depends on some knowledge of the properties of the human eye. It is sensitive only to about one octave of the electromagnetic spectrum; thus the observations are highly selective and possibly biased. The eye's maximum sensitivity at high light levels (fig. 1) is close to the position of

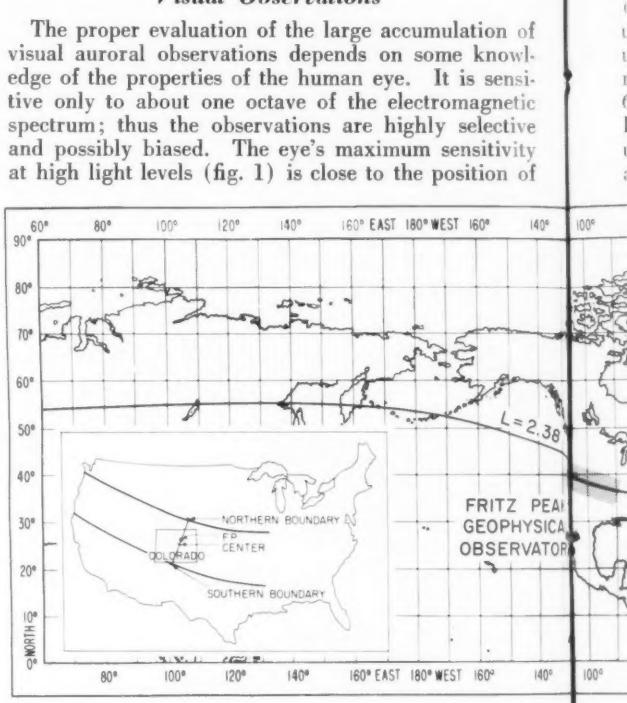


***Figure 2*, an auroral arc was observed at Fritz Peak on 2[illegible]pt., 19[illegible] on the same night in France, leading to speculation that the[illegible]ay ex[illegible] (*bottom left*) shows the typical north-south range of the[illegible]ich n[illegible]**

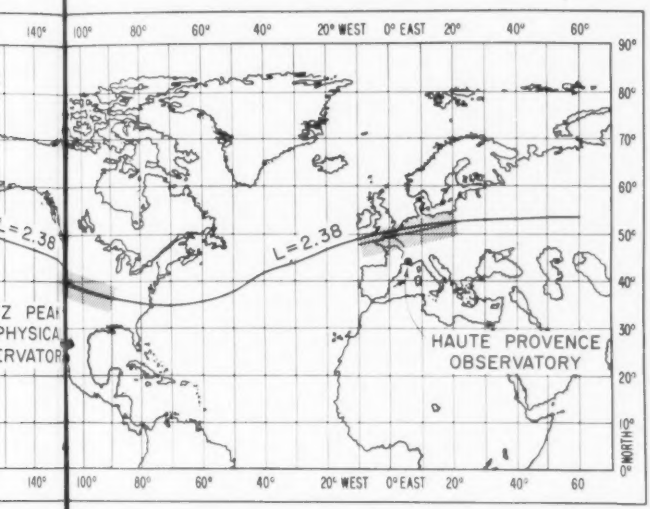
one of the prominent auroral lines, the 5577–A emission of atomic oxygen. According to Chamberlain,[1] for a bright aurora the energy in the 5577–A emission is only 2 percent of the total known optical energy, but 35 percent of the optical energy in the part of the spectrum to which the eye is sensitive (see table). The eye's prejudice in favor of 5577 A makes this radiation responsible for more than half the visual impression of an aurora; therefore, our concept of the aurora is highly subjective—2 percent of a typical aurora's optical energy is responsible for half of the psychological response.

Therefore, it will not be surprising if, with the development of instrumentation capable of detecting radiations to which the eye is relatively insensitive, or even blind, we may be forced to modifications or revisions of the present synoptic picture of the aurora.

ID-LATITUDES

Relative Insensitivity of the Eye to Flux of 6300 A

We are especially concerned here with radiant flux at 6300 A, for which the daylight-adapted eye has a sensitivity 45 percent of maximum (5550 A) and the dark-adapted eye a sensitivity of only 0.33 of one percent (fig. 1). Experienced observers generally agree that under night conditions the radiance (radiant flux per unit solid angle and projected area) threshold for auroral features is ten times as high for flux of wavelength 6300 A (red) as for that of wavelength 5577 A (green). In the units now employed by auroral observers the visual threshold for 5577 A is about one kilo-rayleigh (kR) and for 6300 A is about 10 kR. (The radiance required for a color impression is 20–30 kR regardless of wavelength.) Thus the fact that an area of wavelength 6300 A is not visible means that its radiance is less than 10 kR, and such radiance might easily be visible if the wavelength had been in a more favorable region of the spectrum. Recently the improvement of techniques in photoelectric photometry has made systematic observations of 6300 A radiation possible to intensities as low as 0.01 kR.



k on 2[illegible]pt., 1957, that may have been an extension of an arc observed that the[illegible]ay extend in a complete circle around the earth. The inset of the[illegible]ich may exceed 700 km.

*Absolute intensities of auroral emissions in a bright aurora (Chamberlain)**

Radiation	Intensity	
	ergs/cm²/sec	%
5577 A	0. 36	2. 0
6300, 6364 A	0. 16	0. 9
All other *visual* radiations	0. 20	1. 1
Other UV and IR radiations	17. 3	96. 0
Totals	18. 02	100. 0

*See footnote 1 at the end of this article.

***Figure 3*, the red arc (*shaded region*) lies south of the southern extension of the visible aurora (⊥).**

Discovery of Mid-Latitude Auroral Arcs

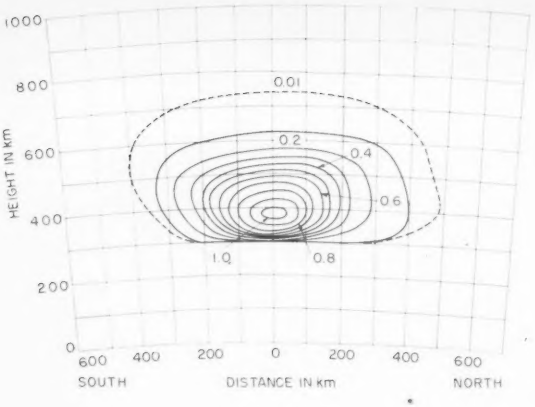
In 1957 Dr. Daniel Barbier,[2,3] French astronomer, noted that his 6300-A photometer sweeping around at a constant angle above the horizon occasionally showed two conspicuous regions of enhanced brightness somewhat as one might observe if he were to sweep across the two opposite feet of a complete rainbow arch.

Other observers in Australia and the United States soon confirmed the existence of these "monochromatic" red arcs.[4] Since they occur in the latitude of the Bureau's Fritz Peak Geophysical Observatory, Franklin E. Roach, Chief of the Airglow and Aurora Section, and his group have the opportunity to observe them directly overhead on frequent occasions.[5,6,7]

Coordinate System

In the description of terrestrial magnetic phenomena a number of different systems have been used to designate position on the earth's surface. Since the earth's magnetic poles are some 11 degrees from the geographic poles, it is obvious that geographic latitude and longitude are not appropriate.

Occasionally it is convenient to use a so-called system of geomagnetic longitude and latitude based upon an idealized picture of the earth's magnetic field due to a simple dipole near the earth's center. However, this idealization is not suitable for rigorous studies. Furthermore, it has been found that the 6300-A arcs follow



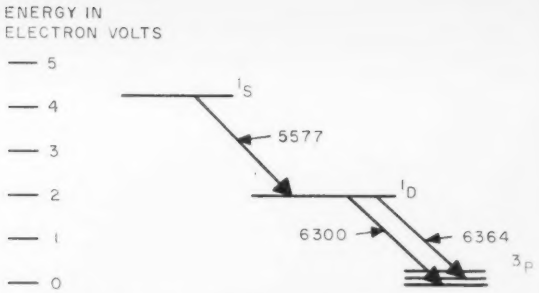


Figure 4, left: **A composite cross section of several arcs. Numerals inside the grid indicate the relative brightness of various portions of the arc.** ***Figure 5, above:*** **Energy diagram for the lowest atomic levels of the oxygen atom. The companion 6264 A radiation, not mentioned in the text, is only about ⅓ as bright as the 6300 A radiation.**

lines of geomagnetic latitude very poorly, but follow the lines of constant sheet parameter, or L, rather well.[8]

Customarily, L is measured in units of the earth's radius, with $L=1$ corresponding to the surface of the earth (fig. 7). In terms of L the CRPL investigators have observed the 6300-A arcs from extreme positions of $L=2.0$ to $L=3.6$, which correspond to approximate geomagnetic latitudes of 45° and 58°.

Extent of the Arcs in Longitude, Latitude, and Altitude

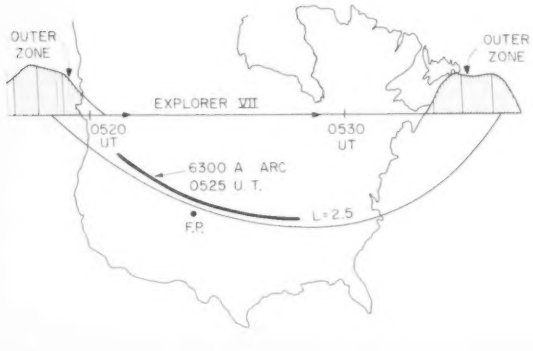
Many of the visual arcs seen regularly in polar regions are only a few kilometers in thickness in the north-south direction. In contrast, the *invisible* mid-latitude arcs extend over several hundred kilometers north-south. A typical width is 700 km. From Fritz Peak individual arcs have been observed to extend over a range from 300 km north to 400 km south, thus including the entire state of Colorado (see insert, fig. 2).

The great extension of the arc in longitude is one of its interesting characteristics. From a given station it can be observed over a circle of 1350 km radius, or 2700 km diameter (for a zenith distance of 80°). From Fritz Peak it is possible to follow an arc from the Mississippi River almost to the Pacific Ocean (see footnote 6). Of the scores of arcs which the Fritz Peak group has observed there has never been any suggestion of a termination or a tapering off. In some cases where the same arc has been observed from three stations in the southwestern United States the observations extend well out into the Pacific Ocean (see footnote 5). Thus direct observation has established the continuity of arcs over some ten percent of a complete terrestrial circle.

On one occasion (Sept. 29/30, 1957) an arc was observed in Colorado at the beginning of an observing night which occurred just as Dr. Barbier, at the Haute Provence Observatory, had completed his night's study of an arc in southern France. The positions of the arc at the two stations indicate that both groups were probably observing the same phenomenon at places separated by 120° in longitude (see fig. 2). This, then, strongly suggests the possibility that the arcs may extend in a complete circle around the world.

The height of the arc has been determined by triangulation on two occasions to be about 400 km. The vertical extension has been found to be from 300 km to 600 km. A composite cross section of several arcs has been worked out by Tohmatsu and Roach (fig. 4).[9]

Figure 6, **data from Explorer VII on Nov. 28–29, 1959, revealed that the outer Van Allen zone was farther "south" than customary. There was a general coincidence of position of the red arc and this zone, suggesting a correlation between the two phenomena.**



Location and Movements of the Arcs

In the IGY–IGC period arcs were recorded at Fritz Peak during some 20 percent of the observing time. They were generally present during periods of significant magnetic activity as geographically discrete features to the south (see fig. 3) of the general *visible* auroras (visible because of the presence of the green, 5577 A, radiation).

Barbier has referred to the arcs as "stable" because of their sluggish movements in space and their slow changes of intensity. This is in strong contrast to visible auroral features which may whip across the sky in seconds and change intensity with bewildering rapidity.

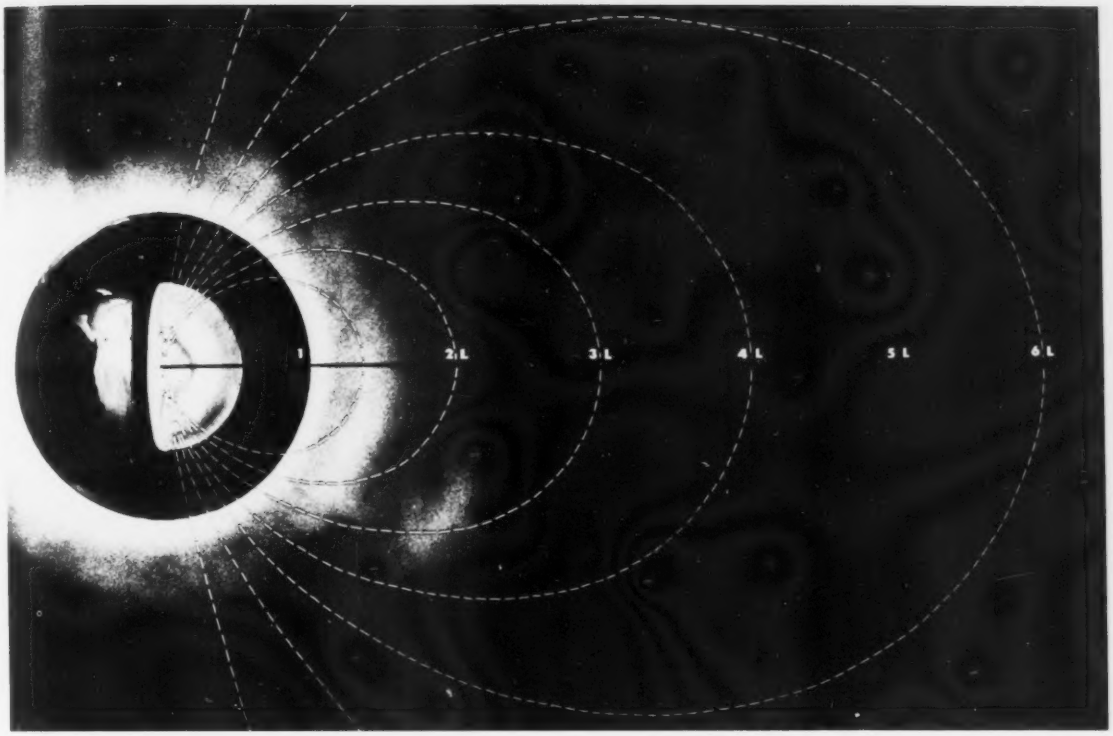


Figure 7, schematic sketch of the earth's magnetic field. Trapped particles remain on surfaces of constant L, L being measured in term of the earth's radius. The auroral arcs occur in the region L 2.0 to L 3.6.

Possible Relationship to the Van Allen Radiation Belts

Four passes of the Explorer VII satellite are pertinent to the study of a conspicuous red arc, observed on November 27/28, 1959.[10] The satellite's counters, sensitive to high-energy particles, detected the outer Van Allen zone. It was definitely farther "south" than customary. There was a general coincidence of position of the red arc and of the outer zone (fig. 6), suggesting a correlation between the two phenomena.

Possible Causes

Apparently, the mid-latitude arcs are large-scale phenomena. The full explanation of the mechanism causing radiation at 6300 A must involve global considerations. In a typical arc the average energy is 3×10^{-10} ergs/cm^3/sec. If our speculation that these invisible arcs encircle the earth is correct, then the total energy output is some 5×10^{14} ergs/sec.

The principal "atomic" feature is the strong preference for a single optical emission, the 6300-A emission due to atomic oxygen (see fig. 5), which requires 2.0 electron volts of excitation energy. The green line, 5577 A, is not emitted to any measurable extent. This indicates that there must be a source of energy somewhere between 2.0 and 4.2 electron volts.

Four speculative suggestions have been made of possible microscopic mechanisms: (1) A heating of the atmosphere by particles ejected from trapped zones leading directly to the excitation of the ^1D level in preference to the ^1S level; (2) an electrical current which would result in conditions similar to those found in laboratory discharge tubes; (3) a photochemical reaction which is enhanced during times of magnetic activity; and (4) direct excitation by particles expelled from trapped zones.

With regard to the third possibility the following reaction has been suggested: [11]

$$NO^+ + e \rightarrow N + O \text{ (excited to } ^1D).$$

The reaction is sufficiently energetic (2.75 ev) to excite atomic oxygen to the ^1D state, but not to the ^1S level.

Whatever may be the microscopic cause of the phenomenon, the intriguing problem remains as to the reason for the grand-scale properties that have been out-

lined. It remains to be determined how kilo electron volt particles can degenerate down to the two-electron volt level without exciting atomic oxygen to the ^1S level (4.2 ev) which would result in the emission of 5577 A.

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[1] Physics of the aurora and airglow *by J. W. Chamberlain, p. 197, Academic Press, 1961.*

[2] L'Activité aurorale aux basses latitudes *by D. Barbier, Ann. de Geophys.* **14,** *334 (1958).*

[3] L'Arc auroral stable *by D. Barbier, Ann. de Geophys.* **16,** *544 (1960).*

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[5] A monochromatic low-latitude aurora *by F. E. Roach and E. Marovich, J. Research NBS* **63D** *(Radio Prop.), No. 3, 297 (Nov.–Dec. 1959).*

[6] Aurora of October 22/23, 1958, at Rapid City, S. D., *by F. E. Roach and E. Marovich, J. Research NBS* **64D** *(Radio Prop.), No. 2, 205 (Mar.–Apr. 1960).*

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[8] Coordinates for mapping the distribution of magnetically trapped particles *by C. E. McIlwain, J. Geophys. Research* **66,** *No. 11, 3681 (1961).*

[9] Morphology of mid-latitude 6300 A arcs *by F. E. Roach and T. Tohmatsu (in press).*

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[11] Relationship between red auroral arcs and ionospheric recombination *by G. A. M. King and F. E. Roach, J. Research NBS* **65D,** *(Radio Prop.), No. 2, 129 (Mar.–Apr. 1961).*

CRPL Aids Missile Tracking

SCIENTISTS of the Bureau's Boulder Laboratories are analyzing errors in radio position measurements and fluctuations in the radio refractive index of the troposphere to determine their correlation. Long-term fluctuations were studied by analysis of punched-card data available in the Radio Refractive Index Data Center [1] of the NBS Central Radio Propagation Laboratory. Short-term fluctuations are being studied by correlating variations in radio transmission time with variations in radio refractive index, using measurements made with an operating model baseline missile tracking system. The correction factors obtained in these studies will be programed into the computer of the MISTRAM baseline missile tracking system, now being built by the General Electric Company for operation near Patrick Air Force Base, in the Cape Canaveral, Fla., area.

Missile Tracking

MISTRAM determines the missile's position by measuring the times required for radio signals to travel from each of several antennas to the missile and back. These antennas are arranged on an orthogonal set of baselines.

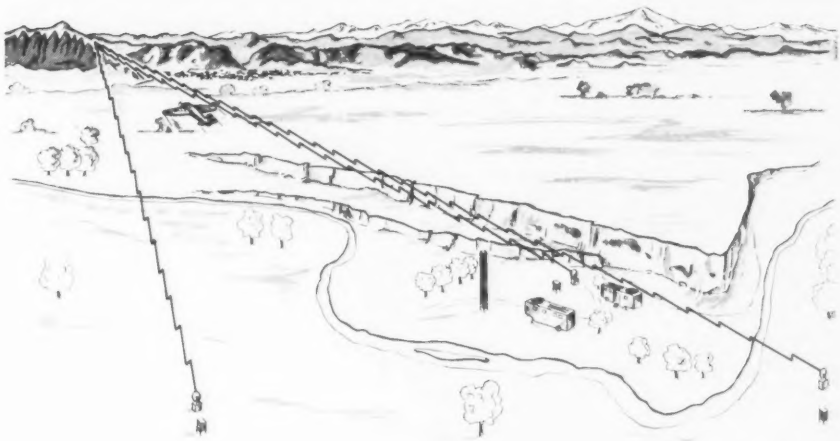
Translating these transit times to distances (and, hence, to position) requires a knowledge of the speed with which the radio signals travel through the atmosphere. This speed, usually expressed in terms of the refractive index, is a function of the composition of the atmosphere along the signal paths. Tracking inaccuracies result from variations in the earth's atmosphere along these paths. The variations consist of both large-scale changes, caused by air mass movements, and short-term changes, resulting from turbulence.

Such tracking errors, introduced by variations in atmospheric refractive index, may become the limiting factor in obtaining the accuracy demanded of new tracking systems by advancing space technology. The development of "second generation" missile tracking systems, such as MISTRAM, near Patrick Air Force Base, Fla., has necessitated a study of the problem of obtaining correction factors to be programed into the system's computer.

The radio propagation engineering staff of the NBS Central Radio Propagation Laboratory (CRPL) was requested to provide estimates of the nature and extent of the atmospheric effects. The problem was attacked by means of two separate studies.

An airborne microwave refractometer is readied for installation in an airplane. This equipment has been used in measuring the radio refractive index of the atmosphere along the paths used for distance measurement on a simulated missile tracking system.

Model test setup simulates actual radio tracking system under evaluation. Antenna in background simulates the missile, while those in the foreground simulate the configuration of baseline tracking stations in the vicinity of Patrick Air Force Base, near Cape Canaveral, Fla. Radio refractive index measurements are being made at the antennas and by means of airborne refractometers (*in aircraft*) along the signal path. Statistical methods will be used to determine correlation between signal transit time and simultaneous measurements of radio refractive index.



Tropospheric Studies

In the first study, a theoretical description of long-term variations of the refractive index for both the homogeneous and inhomogeneous atmosphere was developed by members of the Radio Meteorology section, B. R. Bean, chief. This was done by analysis of all the radiosonde data available in CRPL's Radio Refractive Index Data Center. More than 7,000,000 punched cards stored here contain radio refraction measurements made over a long period of time at many points. Application of statistical methods to this pool of information has made possible a systematic correction of tracking data, based on readily available meteorological parameters. This correction has been obtained in a form suited for use in MISTRAM's high-speed computer.

Short-Term Atmospheric Problems

The other phase of CRPL's attack on the problem is a study of the short-term effects of turbulence. The Lower Atmosphere Physics section, M. C. Thompson, Jr., chief, has constructed a simulated missile tracking system for making this study. The missile is simulated by an antenna mounted on concrete on the side of a mountain behind the Boulder Laboratories. Radio transmissions at microwave frequencies (about 9,400 Mc/s) are used between the "missile" and three "tracking station" antennas 10 miles to the east, arranged to simulate the relative positions of the tracking antennas under construction in Florida.

Radio refractive index measurements at the antenna sites and from aircraft [2] along the transmission path are made simultaneously with radio distance measurements.

Dr. Thompson's group has been evaluating the data collected in this experiment in terms of the magnitude of errors due to short-term fluctuations in the atmosphere. To date, atmospheric effects on range determination have been observed which amount to as much as several feet over a 10-mile path. It has also been found that these effects can often be reduced 80 percent by using appropriate corrections based on simultaneous refractive index measurements.

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[1] Radio refractive index data center, *NBS Tech. News Bull.* **46**, *5 (Jan. 1962).*

[2] Compact microwave refractometer for use in small aircraft *by M. C. Thompson, Jr., and M. J. Vetter, Rev. Sci. Instr.* **29**, *1093 (Dec. 1958). For a description of phase measurements see* Measurments of phase stability over a low-level tropospheric path *by M. C. Thompson, Jr., and H. B. Jones, J. Research NBS* **63D** *(Radio prop.) No. 1, 45 (July–Aug. 1959).*

STANDARD MATERIALS

Revised Primary Standard for Diesel Fuel

THE BUREAU has proposed a new primary diesel reference fuel—2,2,4,4,6,8,8-heptamethylnonane (HMN)—as a replacement for 1-methylnaphthalene, the present low-cetane standard used for determining diesel fuels' ignition quality. The investigation of this hydrocarbon was part of a Bureau program to improve the quality of primary reference fuels.[1]

The ignition characteristics of compression-ignition fuels, i.e., diesel fuels, are evaluated in terms of the "cetane number" scale. Traditionally, the cetane number is numerically equal to the percentage of *n*-hexadecane (*n*-cetane) in a blend with 1-methylnaphthalene that gives the same combustion characteristics when measured in a standard engine as the fuel being evaluated. When the cetane scale was developed, the cetane number of *n*-hexadecane was arbitrarily set at 100 and the cetane number of 1-methylnaphthalene at 0. On the same scale, the highly purified heptamethylnonane, proposed by T. W. Mears, R. M. David, and F. L. Howard, has been found to have a cetane number of 15.[2] Using this scale, the cetane values of commercial products will not be changed. The cetane number of a given fuel calibrated against the *n*-hexadecane-heptamethylnonane scale will then be determined by the following equation:

$$\mathrm{CN} = \frac{\%\ n\text{-cetane}}{100} \times 100 + \frac{\%\ \mathrm{HMN}}{100} \times 15.$$

Reference hydrocarbons have been used for many years as primary standards for determining the combustion characteristics of fuels used in engines operating on both spark-ignition and compression-ignition systems. Primary reference standards for the spark-ignited fuels have been available in high purity for 20 years. Although primary standards for the compression-ignition fuels were also initiated about 30 years ago, until recently the low primary standard was not obtainable in high purity. As the demand for diesel fuel was not great during the early part of this period, there was at first no great need for permanently reproducible reference fuels of high purity. However, production and use of diesel fuels have greatly increased during the past two decades.

When 1-methylnaphthalene in 95 percent purity recently became available in sufficient quantity to be used as a reference fuel, the long-term instability of the cetane versus 1-methylnaphthalene scale became evident. This was primarily due to the failure to achieve reproducible purity of the various lots of 1-methylnaphthalene, and to its lack of stability during storage.

For economic reasons, secondary reference fuels are used in the direct evaluation of commercial fuels. Each lot of these secondary fuels is calibrated against blends of the primary fuels. Members of the American Society for Testing and Materials conducted a special calibration of the secondary fuels against both the older and the newer lots of 1-methylnaphthalene. In this series of tests it became evident that the whole cetane number scale was shifted higher by about two units when the purer 1-methylnaphthalene was used. It was this rather startling development which caused the petroleum industry to consider the replacement of 1-methylnaphthalene with a more stable material that could be prepared with reproducible purity.

To find an improved reference material, the Bureau investigated a number of hydrocarbons and finally selected 2,2,4,4,6,8,8-heptamethylnonane. This material was thought to be the most suitable for several reasons. First, it is rather easily synthesized by the sulfuric acid-acetic acid dimerization of diisobutylene,[3] a commercially available substance. This technique yields only three olefin hydrocarbons in the C_{16} range which are all hydrogenated to one product—2,2,4,4,6,8,8-heptamethylnonane. Thus, a hydrocarbon with high purity is obtained. Large quantities of the heptamethylnonane could be prepared in this manner.

Second, the heptamethylnonane was found to have about the same density and molecular weight as *n*-hexadecane and to be stable in storage. In addition, diesel test-engine performances using high heptamethylnonane (low cetane number) blends were observed to be superior to operations with high 1-methylnaphthalene blends.

[1] *T. W. Mears, R. M. David, and F. L. Howard, ASTM Bull. No. 245, 75 (April 1960).*

[2] *The cetane number of 15 for heptamethylnonane was agreed upon by the Division on Combustion Characteristics of ASTM Committee D-2 after extensive calibration of cetane-HMN scale against both the cetane-1-methylnaphthalene scale and the secondary reference fuels. These calibration tests were performed by member laboratories of the National Exchange Group under ASTM-D-2.*

[3] The structure of tetraisobutylene, *J. N. Cosby, PhD. Thesis, Part I, The Pennsylvania State University, 1941.*

Zirconium Spectroscopic Standard Samples

TWO NEW standard samples of zirconium and one of Zircaloy 2—a zirconium alloy containing a nominal 1½ percent tin—are now available as part of the Bureau's continuing standard materials program. Carefully analyzed and certified for composition and homogeneity, the new standards [1] are designed for calibration in the spectrochemical analysis of certain zirconium and zirconium-base alloys. Issued in the form of disks 1¼ in. in diameter by ¾ in. thick, the standards are suitable for both optical emission and X-ray analysis.

Zirconium is becoming increasingly important today because of its favorable combination of properties required for nuclear reactors—low thermal-neutron cross section, high corrosion-resistance in water, and high-temperature strength. However, the presence of extremely small amounts of certain impurities is detrimen-

TABLE 1.—*Zirconium and Zircaloy 2 Standards*

(All concentrations are in parts per million unless otherwise designated)

Element [b] \ NBS No.[a] designation	1210 Zirconium A	1211 Zirconium B	1213 Zircaloy 2 D
Fe	0.25%	0.10%	0.06%
Cr	95	95	.05%
Ni	8	26	.01%
Sn			1.76%
Al	[c] (60)	(90)	(50)
B	(<0.25)		
Cu	10	44	22
Mn	(5)	(7)	(6)
Si	(30)	(100)	(30)
Ti	(25)	(50)	(30)
W		(40)	
U	1.8	2.3	2.0

[a] Size: Samples are disks 1¼ in. in diameter and ¾ in. thick.

[b] Other elements also contained in the standards: Cd, Co, Hf, Mo, P, Pb, V, Zn, C, O, N, Gd, Yb (the last two are not in Standard No. 1213).

[c] Values in parentheses are not certified but are given for additional information on the composition.

tal to zirconium's use as reactor material. Consequently, stringent specification limits in parts per million have been established for impurities in reactor-grade material.

The standards contain more than twenty elements. Ten of these elements, with their concentrations, are listed for each standard, although not all of the values are certified. Some of the remaining elements may be certified at a future date. Both chemical and spectrochemical methods were used for analyzing most of the elements.

In preparing the standard samples, the basic metal sponge plus the desired minor constituents were triple arc melted in vacuum by the Albany (Oreg.) Station of the U.S. Bureau of Mines. The molten metal was then poured into a graphite mold to form a single ingot, the casting also being done under vacuum. After being cropped top and bottom, the ingot was cut lengthwise to remove the center section, approximately one-fourth of the ingot. The outer sections were then fabricated into rods, annealed, and centerless ground to 1¼ in. in diameter.

Cooperating laboratories, representing the Bureau and producers and consumers of zirconium and zirconium alloys, analyzed composite samples of the finished material. Average values of the results reported by these laboratories are given on a provisional certificate of analysis (table 1) which is issued with each standard sample. The laboratories that cooperated in the analytical program are as follows: National Bureau of Standards; Allegheny Ludlum Steel Corp, Watervliet, N.Y.; Babcock & Wilcox Co., Nuclear Facilities Plant, Lynchburg, Va.; The Carborundum Co., Akron, N.Y.; Columbia National Corp., Pensacola, Fla.; General Electric Co., Knolls Atomic Power Laboratory, Schenectady, N.Y.; Metals and Control, Inc., Attleboro, Mass.; Oregon Metallurgical Corp., Albany, Oreg.; Reactive Metals, Inc., Ashtabula, Ohio; U.S. Atomic Energy Commission, New Brunswick Laboratory, New Brunswick, N.J.; Wah Chang Corp., Albany, Oreg.; and two divisions of Westinghouse Electric Corp., Bettis Plant, Pittsburgh, Pa., and Atomic Fuels Dept., Cheswick, Pa.

The two zirconium and one Zircaloy 2 standards may be purchased for $60.00 per sample from the Standard Sample Clerk, National Bureau of Standards, Washington 25, D.C. Further information may be obtained through the Standard Sample Clerk. The complexity of the homogeneity testing and analytical program has resulted in a price substantially higher than that charged for spectroscopic standard samples previously issued.

[1] *The standards are described in NBS Misc. Publ. 241,* Standard Materials. *This publication may be ordered for 30 cents from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.*

A Stainless Steel for Standard Weights

FOR MANY YEARS brass has been used as the principal material for the standard weights maintained by the various States as reference standards. Brass is nonmagnetic—a prime requisite—and it has a density of 8.4 g/cm³, the weight per unit volume long established in this country for standards of mass. However, it is not an ideal material since it tarnishes and is thus subject to changes in weight. A study has therefore been made at the Bureau to develop a nontarnishable alloy for physical standards of mass.[1]

In the study, conducted by S. J. Rosenberg and T. P. Royston of the thermal metallurgy laboratory, it was recognized that commercial austenitic stainless steel—which is highly corrosion-resistant—could meet the nonmagnetic but not the density requirement, since its weight per unit volume is about 7.9 g/cm³. Of the various heavy elements that might increase the density, tungsten appeared the most promising, even though it could promote the formation of ferrite and hence cause an undesirable increase in permeability. It was anticipated, however, that austenite stability could be maintained by using steels containing a 2-to-1 ratio of nickel and chromium.

In the experiments, several stainless steels of this composition were combined with tungsten by melting in a laboratory induction furnace, and the metal was poured in the form of 1.5-in.-diam bars. A 4-hr homogenizing annealing treatment at 2,000 °F preceded hot working by forging and swaging, in which rods of 0.6 in. diam were produced. The rods were then cut into 6-in.-long specimens for chemical and spectrochemical analysis.

The results of the analysis showed that one of the steels had the characteristics desired for standard weights. Its principal constituents, in percentages by weight, are as follows: Carbon 0.09; manganese 1.7; silicon 1.55; nickel 32.4; chromium 16.2; tungsten 9.9. The density of this steel as hot worked is 8.42 g/cm³ and its magnetic permeability is 1.008.

After this work was initiated, international proposals were made to set the density of mass standards at 8.0 g/cm³. A steel of this density, having the other characteristics necessary for reference standards, has recently been produced commercially. It is now being investigated for possible future use, should the 8.0 g/cm³ density criterion eventually be adopted.

[1] *For further technical details, see* A stainless steel for standard weights *by S. J. Rosenberg and T. P. Royston, ASTM Materials Research and Standards* **1**, *21 (1961).*

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Basic Radio Propagation Predictions for May 1962. Three months in advance. CRPL-210, issued February 1962. 15 cents. Annual subscription: $1.50; 50 cents additional for foreign mailing. Available on a 1-, 2-, or 3-year subscription basis.

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Section B. Mathematics and Mathematical Physics, Vol. **66B**, No. 1, Jan. Mar. 1962

Error bounds for eigenvectors of self-adjoint operators. N. W. Bazley and D. W. Fox.

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Reference tables for 40 percent iridium-60 percent rhodium versus iridium thermocouples. G. F. Blackburn and F. R. Caldwell.

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